

## Cosmic Times: 1993

1

*Cosmic Times* is a series of six posters with classroom lessons that trace the development of our understanding of the nature of the universe during the past century.

This edition, the fifth of the series, features the discovery of anisotropies in the cosmic microwave background (CMB). These tiny variations in the remnant radiation from very early in the Universe eventually formed the structures that we see around us today. By the early 1990s, astronomers have extended the Big Bang theory to include a period of inflation to make the theory better align with observations. The distance scale has been refined based on a class of supernova, allowing distance determinations to ever-further galaxies. In addition, the Nobel prize for physics awarded to a pair of scientists who discovered proof of gravitational waves.

The language in the 1993 newspaper mimics the style of writing that would have appeared in a newspaper at that time. The style is similar to modern-day newspapers, and should be easier to read than previous editions; though, the concepts continue to get harder. The poster also shows a layout that mimics the papers of the time (note the introduction of color); however, we have taken some creative license to make it more readable in a classroom setting.

The *Cosmic Times* website, <http://cosmictimes.gsfc.nasa.gov/>, provides a complete teacher guide for this poster and the accompanying lessons. There you can also find two newsletter versions of the poster: one of the newsletters contains the same text as the poster, while the other translates the text to a slightly lower reading level. The web site also includes a glossary. We provide here a summary of the articles, a synopsis of the lessons, and one of the lessons.

## What’s the Problem with Isotropy?

4

Suggested Grade Level(s): 10-12

Estimated class time: one 45-minute class period (assuming students have already read and discussed the 1993 *Cosmic Times* article, “Baby Universe’s 1st Picture”)

### Summary

This lesson targets the significance of discoveries made with the COBE satellite in 1993. To fully support Big Bang theory, small variations in the distribution of Cosmic Microwave Background radiation (CMB) needed to exist. These anisotropies were not able to be detected prior to 1993 because the necessary technology had not yet been developed and deployed.

Students will participate in an Engagement activity which demonstrates how very small variations in a pattern are unrecognizable without the use of technology. In the Exploration and Explanation sections of the lesson, students will understand why Big Bang theory requires variations in CMB (anisotropy); they also examine the significance of both anisotropic and isotropic observations. Finally, in the Extension and Evaluation sections, students complete activities that further reinforce and demonstrate their understanding of the material presented.

### Objectives

Students will:

- Understand and correctly use the terms anisotropic and isotropic.
- Explain the significance of, and necessity for anisotropic CMB radiation to support the Big Bang theory.
- Demonstrate the problem that isotropic CMB radiation created for the Big Bang theory.

### National Science Education Content Standards

- NS.9-12.1 SCIENCE AS INQUIRY
- NS.9-12.4 EARTH AND SPACE SCIENCE
- Origin and evolution of the universe

## II. Exploration

7

- Provide each pair of students with a balloon and a pen or marker.
- Instruct students to flatten out the balloon, and draw approximately 50 dots in a small area on one side of the balloon using a pen or marker. If golf or ping-pong balls are available, students can drape the balloon over the ball and then draw the dots. No particular pattern to the dots is needed, but they should be small (2 mm maximum diameter), dark and closely spaced.
- Have students inflate their balloons and pinch the end to hold the air in.
- Instruct students to consider color as a measure of temperature. Pink areas are one temperature and gray (pen-marked) areas are another temperature.
- ASK: Which side of the balloon is similar to the first view of the piece of colored paper? Ensure students understand the unmarked side of the balloon is similar. The surface appears smooth and without texture or structure.
- ASK: What would this infer about the temperature of the balloon on this side?
- Students should recognize this would mean all regions of the balloon (on this side) have the same temperature.
- Introduce the term *isotropic* to describe this condition.
- Have students observe the other side of the balloon where they drew the dots.
- ASK: What would you infer about the temperature of the balloon in the area where you drew the dots?
- When the balloon expands the dots fade, but there are still distinct differences in color, grading from pink to light gray to dark gray. Therefore students should recognize the temperature is not the same in all regions.
- Introduce the term *anisotropic* to describe this condition.
- Instruct students to carefully watch the dots while they allow the air to quickly escape from the balloon. They will observe the dots moving closer together.
- ASK: If someone else had drawn the dots, and they moved so close together that you could not tell they were individual dots, would you describe the temperature in this area of the balloon as isotropic or anisotropic?
- ASK: How would this be similar to your experience with the colored paper?

## Summary of the Articles

(for more information, see

[http://cosmictimes.gsfc.nasa.gov/1993/guide/teachers\\_guide.html](http://cosmictimes.gsfc.nasa.gov/1993/guide/teachers_guide.html))

### Baby Universe’s 1st Picture

In the early 1990s, the COBE satellite confirmed the spectrum of the cosmic microwave background to be a perfect black body, as predicted by astronomers. It also made the first complete map of the tiny fluctuations in the temperature of the background. This discovery was a watershed event. Astronomers had known that this remnant radiation from the Big Bang could not be infinitely smooth. This is because we have a “lumpy” universe now, with clumps of matter that form structures we see today. The discovery of the anisotropy confirmed astronomer’s ideas about the Big Bang.

### Pancake or Oatmeal Universe – What’s for Breakfast?

Despite the fluctuations discussed in the “Baby Universe” article, the microwave background is remarkably smooth. This brief sidebar discusses the differences between the apparent smoothness of the distribution of matter in the early universe to lumps of matter (in the form of galaxies) we see today. It sets up the “Inflation in the Universe” article.

### Inflation in the Universe

This article explains how inflation theory addressed a problem faced by the Big Bang – the universe is too big for the cosmic microwave background to be as smooth and uniform as it is. To solve this, astronomers introduced a very short period of very rapid expansion just after the Big Bang. An underlying message of this article is that theories, such as the Big Bang, often undergo revision and changes.

### Dark Matter Hunt Heats Up

In the 1990s, the evidence for dark matter expanded to include observations of hot X-ray gas in a group of galaxies. The observations showed that the visible mass of the galaxies was insufficient to hold such energetic gas in place. Hence, dark matter must be present. While previous *Cosmic Times* editions have touched on dark matter, we find that exploring in wavelengths other than visible light provides compelling new evidence.

### Fool-Proofing Galactic ‘Candles’

This article continues the story of how astronomers refine their “standard candles” to determine distances to far away galaxies. This article picks up the story of supernovae and different types of supernovae discussed in the 1955 edition of *Cosmic Times*. In the early 1990s, astronomers refined their understanding of Type Ia supernovae so that they could be more reliably used as standard candles. Type Ia supernovae can be observed in objects at much further distances than the other standard candle, Cepheid variables, discussed in earlier editions of *Cosmic Times*. This development sets up a key tool that will play an important role in the 2006 edition of *Cosmic Times*.

### Pulsar Gravitational Waves Win Nobel Prize

In 1993, the Nobel Prize for physics was awarded to Russell Hulse and Joseph Taylor of Princeton University. The prize was awarded for their discovery of the first pulsar in a binary system and subsequent work using the arrival times of pulses from the pulsar to give the first evidence of gravitational waves. This article illustrates that scientists continually test their theories, and that after nearly 80 years Einstein’s theory of relativity continues to pass those tests.

## NS.9-12.5 SCIENCE AND TECHNOLOGY

## NS.9-12.7 HISTORY AND NATURE OF SCIENCE

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

### Knowledge Prerequisite

- Students should be familiar with the basic tenets of the Big Bang Theory:
  - An indescribably hot-dense “ball” of energy “exploded” and expanded.
  - As it expanded, all of the energy cooled and some of it became matter.
  - Over time, gravity collected the matter into the galaxies, stars, planets and other objects we observe today.
  - Evidence supporting the theory includes relic background radiation from the explosion (cosmic microwave background), and red shifts of galaxies outside of the Local Group.
- Students should have read and discussed the 1993 *Cosmic Times* article, “Baby Universe’s 1st Picture”
- It may also be helpful if the students are familiar with the 1965 *Cosmic Times* article, “Murmur of a Bang”

### Teacher Background/Notes

The success of this lesson is strongly influenced by the teacher’s ability to engage all students in the dialogue. Encourage as much participation as possible while monitoring time. The lesson can be accomplished within a standard 45-minute period when students are held to strict time limits for each part of the lesson.

A clear understanding of the terms isotropic and anisotropic is needed to effectively deliver the lesson. A physical property that is isotropic is the same in all directions regardless of the direction of measurement. A physical property that is anisotropic is not the same in all directions. Reference to this is made in the *Cosmic Times* article “Baby Universe’s 1st Picture.”

**It is important to first survey students and to check with the school nurse to learn about any students who might have a latex allergy. If this is a possibility, latex-free balloons must be used in the Exploration section.**

## III. Explanation

8

- ASK: Which part of the balloon could represent a view of the universe ... the smooth part that’s the same everywhere, or the part with the dots?
- If necessary, help students understand the area of the balloons with the dots represents a view of the universe. We see galaxies dispersed throughout space ...
- EXPLAIN: When Penzias and Wilson discovered relic Cosmic Microwave Background (CMB) radiation in 1965, their measurements found this radiation coming from all areas of space. In 1991, COBE (NASA’s Cosmic Background Explorer satellite) also measured the temperature of the radiation and found it to be smooth and isotropic, just as Penzias and Wilson did.
- EXPLAIN: Although Penzias and Wilson’s discovery of the CMB was generally highly supportive of the Big Bang theory, a smooth (isotropic) distribution of CMB presented a problem for the theory. This would be equal to a pink balloon with no dots and a universe with no galaxies.
- ASK: If all the relic CMB radiation is the same temperature, what do you infer about the distribution of the energy at the moment of the Big Bang?
- Guide students to understand that the explosion would have evenly and smoothly distributed energy in all directions.
- ASK: If matter formed from the energy, what would this infer about the distribution of matter in the universe?
- Guide students to understand that matter would also be smoothly and evenly distributed.
- ASK: Do we observe a smooth and even distribution of matter? Of course students should readily respond no ... matter appears to be clustered in galaxies separated by large areas of space.
- At this point it is likely that some students will want to attribute the collection of matter into galaxies, etc. as a result of gravity acting on matter. Guide them to consider: Would gravity have accomplished this structure if all the energy (matter) was smoothly and evenly distributed at the moment of the Big Bang and then continued to expand in a perfectly smooth and even pattern? With guidance they can see that this would not occur. There would need to be irregularities in the distribution of the energy (matter) at the moment of the Big Bang which would ultimately allow gravity to act to bring masses together.

## Summary of 1993 Cosmic Times Lessons

3

Each of the lessons uses elements of the 5E model of Engage, Explore, Explain, Elaborate, and Evaluate. These lessons may be downloaded from <http://cosmictimes.gsfc.nasa.gov/1993/1993.html>

### Raisin Bread Universe (grades 7-12)

Students use the “Inflation in the Universe” and “Pancake or Oatmeal Universe” articles to examine the idea of inflation in the Universe. The students then observe a bowl of oatmeal to explain the lumpiness and smoothness of the Universe, and use rising raisin bread dough as a model for the expansion of the Universe.

### What’s the Problem with Isotropy (grades 10-12)

This lesson illustrates the significance of the discoveries made by COBE. Students first demonstrate how small variations in pattern may be unrecognizable without technology. They also understand why variations in the microwave background are important for the Big Bang theory. This lesson is included below.

### Gravitational Waves (grades 11-12)

Students explore the properties of waves and create a model of gravitational waves. Students understand how gravitational waves were discovered by Nobel Prize winners Hulse and Taylor.

### Melting Ice (grades 7-12)

Students explore a discrepant event when they design an experiment to measure the rate that ice melts when in pure water versus in salt water. Students realize that a carefully designed experiment may yield unexpected results, and the addition of “new technology” may clarify previously unknown factors.

### Dark Matter NASA Conference (grades 9-12)

Students explore the evidence for dark matter by calculating the escape velocity from different objects, and then by using the measurements made by the ROSAT X-ray satellite for a small group of galaxies.

## Materials

- Small (approximately 3 cm square) sections of colored graphics cut from magazines. One per student. Each piece should be a solid color. Check carefully with a hand-lens to ensure the pictures are offset-lithographs that show a textured ink pattern when magnified. Lighter colors work better than saturated colors.
- Round, solid color latex balloons (see precaution above). One per two students. Pink works nicely.
- Black medium point, ball-point pens or black permanent markers. One per two students.
- (Optional) Golf balls or ping-pong balls. One per two students.

## Procedure

### I. Engagement

- Hand out sections of colored graphics taken from magazines and ask students to examine the colors.
- ASK: Does the texture of the colors appear to be smooth and consistent, or is there any pattern or texture apparent? If the color of the sections is fairly consistent, students should assess the color as smooth and lacking any texture.
- Provide hand-lenses and, if necessary, demonstrate how to use these effectively. Provide supplemental light if needed.
- Have students carefully re-examine the color sections using a hand-lens to see if the color still appears smooth, or if a texture can be seen.
- Using hand-lenses, students should be able to see there is a texture to the color. The texture is fine enough that the colors seem to blend together to form a uniform appearance.
- Review with students: the differences in the pattern of the color are only visible with the use of technology that improves our ability to observe something we can’t normally “see.”
- Explain that advances in technology allowed us to “see” very subtle variations in radiation in space; these small variations were critically important in terms of providing further support for the Big Bang theory.

- ASK: What is the problem with the observation that all the relic CMB radiation is smooth?
- Guide students to understand that the CMB should not be smooth, based on our observation that the distribution of matter is lumpy.
- ASK: What would you expect to find about the temperature of the relic CMB radiation?
- Guide students to understand that it should not be smooth and even, but rather anisotropic, or “lumpy.” Only a very small amount of “lumpiness” would have been needed in this early universe to create the distribution of matter we observe in the universe today. In 1993, COBE released its second result that showed this lumpiness.

### IV. Extension

If desired, engage students in a further discussion of how discoveries feed into technology development (such as the need to find anisotropies in the CMB led to the development of a NASA mission to search for those anisotropies).

An interesting question to pose to students is “Did the scientists find what they were looking for because they were looking for it or because its really there?”

### V. Evaluation

Have students work in partners to develop posters or story boards which demonstrate the following points:

- Why the structure of the Universe observed today implies anisotropic relic CMB radiation should be observed.
- Why galaxies, stars, planets, etc. would not exist if the relic CMB radiation really was isotropic.

9